Non-silicate minerals in garnet-bearing mafic granulites from Skallevikshalsen in the Lützow-Holm Complex of East Antarctica

Kazuki Takahashi[1], Toshiaki Tsunogae[1,2]
[1] *Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki 305-8572, Japan*
[2] *Department of Geology, University of Johannesburg, Auckland Park 2006, South Africa*

Non-silicate minerals such as oxide, sulfide and native minerals are common accessory minerals in granulite-facies rocks. However, they, particularly sulfide minerals, easily change their compositions and assemblages by phase transition, exsolution and crystallization of new phases, and replacement of original phases at lower temperatures. Therefore, studies on behavior of non-silicate minerals during high-grade metamorphism are limited. In this study, we perform petrographic and mineral chemical studies of non-silicate minerals in several garnet-bearing mafic granulites from Skallevikshalsen in the Lützow-Holm Complex of East Antarctica to reveal their evolution during granulite-facies metamorphism.

The studied rocks dominantly occur as boudinaged lenses or layers in quartzo-feldspathic and metasedimentary gneisses. Their whole-rock geochemical data show within-plate and/or E-MORB affinities, suggesting that their protoliths were at least formed during plume-related magmatism probably under within-plate setting. The rocks can be separated into two groups based on matrix non-silicate minerals: sulfide-rich samples, and sulfide-poor or sulfide-free and graphite-bearing samples. In both groups, oxides are the main non-silicate minerals and most of them are ilmenite.

Two sulfide-rich samples are used in this study. One is magnetite-free Cu sulfide-rich sample, and another is magnetite-bearing Fe sulfide-rich sample. The matrix sulfide minerals of the Cu-rich sample are mainly chalcopyrite and bornite. Few pyrrhotite also exists. Chalcopyrite-bornite grains consist of bornite with chalcopyrite exsolution lamellae surrounded by chalcopyrite, suggesting they were originally bornite-chalcopyrite solid solutions. Bornite-free chalcopyrite grains contain several extremely fine-grained minerals such as pentlandite, Ag-Ni-Fe-S minerals (argentopentlandite?), Ni-Bi-S minerals (parkerite?), Pd-Bi minerals (froodite?), and Ag-Se minerals (naumannite?), which are considered to be exsolution phases. Chalcopyrite also occurs along cracks of silicates (mainly quartz) like secondary inclusions, suggesting they were mobilized after peak metamorphism. A few secondary pyrite and magnetite which might have been formed by oxidation reactions occur around chalcopyrite grains.

Inclusion sulfides of the sample are rounded polyhedrons regardless of their hosts (mainly garnet and amphibole, and also plagioclase and pyroxene), and can be divided into two groups based on their mineral assemblages: Fe-rich inclusions (pyrrhotite (~Fe_9S_{10}) + chalcopyrite ± pentlandite ± sphalerite ± troilite (~FeS)), and Cu-rich inclusions (chalcopyrite + bornite ± pentlandite ± sphalerite ± Cu-S minerals ± native copper). Fe-rich inclusions are similar to those reported by Kawakami et al. (2006) and are thought to have been monophase solid solutions (pyrrhotite solid solutions) at higher temperatures. Sphalerite and troilite are considered as exsolutions after chalcopyrite and pyrrhotite, respectively. As partial melting of chalcopyrite + pyrrhotite association does not occur within the range of normal metamorphism (Tomkins et al., 2007), inclusions are considered to have existed before high-grade metamorphism. On the other hand, although Cu-rich inclusions may also have been monophase solid solutions (bornite solid solutions) at higher temperatures, the chalcopyrite + bornite assemblage start to melt at lower temperature (~800 °C, at 1 bar; Tomkins et al., 2007). Therefore, the Cu-rich inclusions might have been crystallized sulfide melt incorporated during near-peak metamorphism.

The matrix sulfide minerals of the Fe-rich sample are mainly pyrite, and chalcopyrite occurs within or adjacent to pyrite. Pyrite sometimes contain sphalerite. Vein pyrite related to symplectite occur around oxides, suggesting fluid activity after symplectite formation (depression). As pyrite breaks down into pyrrhotite + S_2 at higher temperature, it is presumed that pyrite was formed after peak metamorphism by oxidation or sulfidation reactions. Inclusions are similar to Fe-rich inclusions as discussed above, and their assemblages are pyrrhotite + chalcopyrite ± pentlandite ± magnetite.

As discussed above, assemblages of sulfides differ considerably between two samples, and the Cu-rich sample is 4 times richer in Cu than the Fe-rich sample as to bulk rock chemistry. As Ni- and PGEs-bearing minerals occur in the Cu-rich sample, we consider that Cu was derived from fractionated and plume-related mafic magma or segregated sulfide melt together with Ni and PGEs during protolith formation.

Oxides in the graphite-bearing rocks are only ilmenite, and sulfides mainly occur as inclusions. Graphite exists cutting matrix minerals such as garnet and clinopyroxene, suggesting infiltration of C-bearing fluid after peak metamorphism. The fluid might have been derived from adjacent marbles. It is suggested that the rocks underwent retrograde metamorphism under reductive environment relative to the magnetite- and pyrite-bearing sample discussed above.

References

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